Factors Affecting the Performance of Tiger Trout in Utah's Reservoirs

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Differences between Version 1 and Version 2 of this summary:

- Data from 2 additional reservoirs has been added.
- A new variable encompassing the amount of littoral area (surface area : maximum depth ratio) was added. This variable replaces both the surface area and maximum depth variables used in the original analysis.
- We lack a measure of temperature. In the original analysis latitude was used as a temperature surrogate. Elevation and reservoir surface area also effect temperature (surface area used because we don't have storage capacity data from every reservoir). In this version we used ordination to create a single variable that encompasses the combined effects of latitude, elevation, and surface area. It is assumed that this combined variable is better than latitude alone at approximating temperature.
- Combined, these changes mean that the numbers in the tables and the conclusions of the study have changed since Version 1 was emailed to the managers.

Summary: In this study we used data from 16 reservoirs and evaluated factors that affect the performance (length, condition, catch per unit effort, biomass, and survival) of tiger trout. The factors evaluated included measures of reservoir morphometry, reservoir production, stocking history, intraspecific competition, competition with other salmonids, competition with non-salmonids, and total competition (combined effects of intraspecific, salmonid, and nonsalmonid competition). Anywhere between 0 and 64% of the variation in tiger trout performance was explained by these factors. Of the metrics evaluated, lake production (temperature and secchi depth) was the best predictor of tiger trout success. Average tiger trout length, catch per unit effort (CPUE) and biomass (measured as % community composition) all increased with both temperature and secchi depth. CPUE of fish >380 mm (15 inches, arbitrarily set as "memorable length" from brown trout PSD calculations) was also strongly influenced by reservoir production and the combined effect of temperature and secchi depth explained 64% of the variation within the data. The condition (K) of tiger trout tended to increase as the percent biomass of other salmonids within the community increased. The CPUE of tiger trout increased as the number of tiger trout stocked/ha and the average length of tiger trout at the time of stocking increased. Finally, growth and CPUE of fish > 380 mm decrease with increasing rainbow trout density, suggesting that rainbow trout somehow compete with tiger trout. Our results show that reservoir morphometry, intraspecific competition, and competition with non-salmonid fishes have little effect on tiger trout performance. Stocking more tiger trout and larger tiger trout leads to increases in the numbers of sub-catchable and catchable tiger trout but does not lead to higher CPUE of "memorable" (i.e., >380 mm) fish. Instead, tiger trout appear to perform best in warmer waters that are relatively clear. Also, tiger trout tend to perform well in reservoirs where other salmonid species also perform well.

Background/Objectives: The performance of tiger trout varies considerably across Utah's reservoirs. Tiger trout perform well and are popular with anglers in many reservoirs. Yet, there are reservoirs where tiger trout are stocked and inexplicably perform poorly. The goal of this study was to determine what factors predict the success of tiger trout within a reservoir and to assess the effect of various management actions on tiger trout success. There were eight main questions that we hoped to address with our research:

1. Whether reservoir morphometry (i.e., temperature, depth, surface area, etc.) can be used to predict tiger trout success
2. The effect of reservoir productivity on tiger trout success
3. The effect of other fish species on tiger trout performance
4. Whether increasing the size of fish stocked or stocking numbers can help improve tiger trout catch rates
5. How prey availability influences tiger trout success
6. The effects of angler harvest on tiger trout performance
7. The potential impacts that tiger trout have on other fish species
8. Whether past tiger trout performance and stocking history can be used to predict future tiger trout success

Methods:

Sixteen Utah reservoirs (Table 1) were selected for this study. The reservoirs were selected through evaluation of records collected by the Utah Division of Wildlife Resources. Initially, a list of 36 reservoirs was compiled. This list included every reservoir in the state that was stocked with tiger trout during at least 3 years out of a range of years spanning from 2009-2012. Once this list was compiled, it was compared to agency fall gill net records to determine which reservoirs had been surveyed at least once during this same range of years. The evaluation of gill net records further pared the list down to 16 reservoirs (Table 1). These 16 reservoirs are scattered throughout Utah and encompass a wide range of environmental conditions. All 16 reservoirs are considered cold or cool water fisheries and salmonid fishes compose the majority of the sport fish biomass in each reservoir. Salmonid fishes are regularly stocked into all of these reservoirs at either 75 or 150 mm total length. Stockings typically occur during late May-early July. The fall gill net surveys typically occurred in August-October.

Using the available data we were able to derive several environmental variables that described each reservoir. The variables evaluated included metrics of reservoir morphometry (latitude, maximum depth, and surface area), production (chlorophyll α concentration, dissolved phosphorous concentration, and secchi depth), tiger trout stocking characteristics (average number stocked per hectare, average length at time of stocking, average date when tiger trout were stocked), intraspecific competition (tiger trout biomass), interspecific competition (combined biomass of all salmonid species other than tiger trout), and competition from non-salmonid species (combined biomass of all non-salmonid species). For our analyses, we took data that was available from 2009-2012 and computed a mean for each metric for each reservoir. Reservoir morphometry data was provided by the Utah Division of Water Quality (Judd 1997). Reservoir production data was taken from the United States

Environmental Protection Agency STORET Data Warehouse (EPA 2013). This warehouse is a repository of data that is collected from a variety of Federal and State agencies. All agencies used standardized sampling methods. Unfortunately, most of the data available in this warehouse was collected prior to our sampling years (2009-2012). For our analyses, we took all data that was available from 2000-2012 and computed a mean for each metric for each reservoir. Each mean is based on 14-104 (average = 47) separate sampling events. Thus, despite that the majority of the data in the STORET warehouse was collected prior to our sampling years, we feel that we were able to derive a robust estimate of each production metric for each reservoir. The tiger trout stocking metrics were calculated using records kept by the Utah Division of Wildlife Resources.

All of the fish competition metrics (% total fish biomass that tiger trout compose, % total fish biomass that all other salmonids compose, and % total fish biomass that non-salmonid fishes compose) were calculated using fall gill net data collected by the Utah Division of Wildlife Resources. The same data was used to calculate tiger trout catch per unit effort (CPUE; #/net-night), total length, and Fulton's condition factor (K; Anderson and Neumann 1996). Data was averaged across years to produce a single metric for each reservoir. Only the relevant years were included in the analysis. For example, if a reservoir was stocked with tiger trout in 2009-2011, the 2012 gill net data was excluded. The gill net data was collected during fall surveys that are standardized for each reservoir. Traditional 5 panel gill nets (total net length = 40 m; Hubert 1996) were used for each survey. Nets were set perpendicular to the shore with the smallest mesh panel set on the shore. Both floating and sinking nets were used. Nets were set at the same location within a reservoir each year. Nets were allowed to collect fish overnight. Between 3 and 8 nets were set, depending on reservoir. Species, total length, and weight were determined for each fish that was collected. Biomass estimates for each species represent the average percentage, by weight, that each species comprised in the gill nets. Finally, a crude metric of survival of stocked fish was derived by dividing the catch per unit effort of tiger trout <254 mm (10 inches) by the average number of tiger trout stocked/ha.

Prior to performing any analyses using these data, normality was evaluated using QQ-plots and Shapiro-Wilks tests (Kuehl 2000) Logarithmic and Box-Cox transformations were used as necessary. These data were analyzed in several steps. First, univariate correlations were performed among the tiger trout metrics (length, condition, survival, biomass, and CPUE) with each environmental variable. Next, we then constructed 7 models using the environmental (independent) variables (Table 2). The models evaluated the effects of reservoir morphometry, reservoir production, tiger trout stocking characteristics, intraspecific competition, competition from other salmonids, and competition from non-salmonid species. In addition, the additive effect of all three competition metrics (intraspecific, salmonid, and non-salmonid) was evaluated. Prior to performing any data analysis, correlation analysis was used to ensure that all variables included within a model were not correlated with one another (all $P \geq 0.13$). Variables were added to create additive linear models that evaluated six different tiger trout performance metrics (dependent response variables): 1) average total length, 2) average Fulton's condition factor (K), 3) average survival, 4) average % community biomass, 5) average CPUE, and 6) CPUE of fish larger than 380 mm total length (15 inches, arbitrarily set as "memorable" length used in brown trout RSD calculations). Separate analyses were performed for each response variable. We used a sample size corrected AIC analysis (AIC_c) to rank the relative contribution of all 7 models in explaining these response variables. Models with ΔAIC values <2.0 were considered equally parsimonious. To prevent spurious effects, when percent biomass was evaluated as a response variable, catch per unit effort was used in place of biomass in the models shown in Table 2. In addition to performing AIC, the adjusted r^2 value of each model was determined and the relative contribution of each variable was evaluated by computing β weights. All analyses were performed using R (Hornik 2013). An α level cutoff of <0.05 was used when evaluating the significance of any individual model.

Water temperature was not measured in any of the reservoirs. It is predicted that temperature could be an important factor affecting tiger trout performance. Reservoir latitude, elevation, and surface area are all metrics that could affect reservoir temperature. To compensate for the lack of temperature data, a principle components analysis (PCA; Gotelli and Ellison 2004) was used to ordinate the variance explained by these three variables. This was done because incorporating all three variables would have increased the "k" value in the AIC analysis, decreasing the likelihood of the "lake production" model being significant. This ordination allowed us to create a single variable that roughly encapsulates the effect of these three components on reservoir temperature. We used loading scores from the first principle component to compute this variable and this principle component explained 52% of the variation among these three variables. Throughout this analysis we call this new ordinated variable "temperature". High values of "temperature" are associated with higher latitudes, higher elevations, and larger surface areas. Thus higher (or positive) "temperature" values are actually expected to have cooler temperatures than reservoirs with lower (or negative) "temperature" β weights.

The "other salmonid competition" model (Table 2) contains the combined effect of all salmonids other than tiger trout. All species were combined in this model because separating the species diminishes the strength of the AIC analysis (by increasing the K variable in the AIC analysis). To gain a further understanding of the effect of various salmonid species, additional additive multiple regression models were constructed to explain the effect that rainbow trout, cutthroat trout, and "other trout" have on tiger trout performance (length, condition, survival, biomass, and CPUE). Rainbow trout and cutthroat trout were considered because they were present in most (>75%) reservoirs. "Other trout" is the combined biomass of splake, brown trout, brook trout, and kokanee salmon. These species were present in 1-2 reservoirs each. The effects of individual "other trout" species cannot be evaluated because these species were found in too few of the study reservoirs.

Finally, to determine whether the number of tiger trout stocked can predict future tiger trout CPUE, additional additive linear regression models were constructed. Two sets of models were fit. The first set was used to predict whether the number of fish stocked (#/ha) one year can predict tiger trout CPUE the next year. Eight reservoirs were used in this first set of models. The second set of models was used to determine whether the CPUE of tiger trout can be predicted using the number of fish stocked during the two previous years. This set of models included data from six reservoirs. The CPUE of tiger trout from the previous year (for the first set of models) and the CPUE from two year previous (for the second set of models) was used as a covariate to control for initial population size. For this analysis we could not use data from all 16 reservoirs because some reservoirs were sampled infrequently during the study period.

Results and Discussion:

There were eight main questions that we wished to address with our analysis. The results of the correlations, AIC analysis, and linear models used to address these questions are shown in Tables 3, 4, and 5.

1) Can reservoir morphometry predict tiger trout performance?

> Overall, the three reservoir morphometry metrics assessed (maximum depth, surface area, and the surface area : depth ratio) were poor predictors of tiger trout performance (all $P \geq 0.18$; Table 3). Although not statistically significant (all $P \geq 0.37$), the correlations among the tiger trout performance metrics and reservoir surface area : depth ratio were negative indicating that tiger trout may perform best in shallow (relative to surface area) reservoirs. The adjusted r^2 values for reservoir morphometry were 0.01 for all tiger trout metrics, indicating that morphometry explained very little variation within the data. Reservoir morphometry was deemed parsimonious in the AIC analysis when tiger trout survival, % biomass, and CPUE were evaluated (Table 4). Adjusted r^2 values, however show that none of the models evaluated for these performance metrics were particularly strong. Thus, overall, we do not feel that reservoir morphometry is a particularly good predictor of tiger trout success.

2) How does the productivity of a reservoir affect tiger trout performance?

> We found that reservoir productivity was a good predictor of tiger trout growth, biomass, CPUE, and CPUE of fish > 380 mm (Table 4) whereas it was a poor predictor of condition and survival. Typically performance increased with temperature and Secchi depth. The effect of temperature on tiger trout performance is difficult to assess given that temperature was not directly measured. Instead, temperature was estimated using information on reservoir latitude, elevation, and surface area. The negative correlations in Table 3 indicate that tiger trout perform best in small reservoirs that sit at both a low latitude and elevation. The strongest temperature correlations were with tiger trout length and CPUE > 380 mm (both $P < 0.07$). Secchi depth was strongly correlated with CPUE and CPUE > 380 mm (Figure 1; both $P \leq 0.04$). Based on this figure it appears that tiger trout performance at Secchi depths > 2.6 m is better than those at lesser Secchi depths. These data suggest that tiger trout are visual feeders and that they perform best in clearer reservoirs.

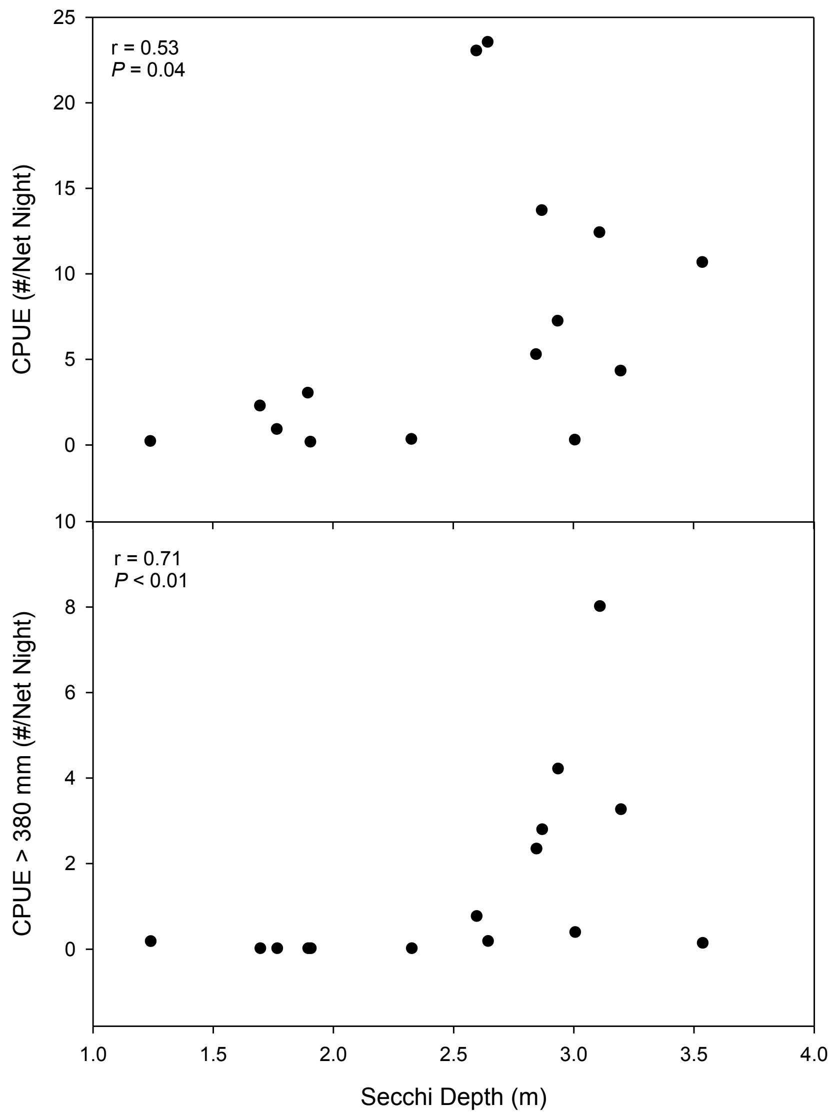

Figure 1: Relationship between Secchi depth and total tiger trout CPUE (top panel) and CPUE of tiger trout > 380 mm TL (bottom panel). The correlation coefficients (r) and *P*-values for these relationships are provided.

3) What effect do other fish species have on tiger trout performance?

The univariate correlations (Table 3) indicate that competition with other fish species has some effect on tiger trout performance. There was tendency ($P = 0.06$-0.08) for the CPUE of tiger trout > 380 mm to decrease with increasing rainbow trout biomass and increasing biomass of all salmonid species combined. The % biomass of tiger trout also tended to decrease ($P = 0.09$) with increasing rainbow trout biomass. This correlation is not surprising given that these variables must co-vary and that fewer tiger trout would be expected in reservoirs with a high abundance of rainbow trout. Finally, the average length of tiger trout tended to decrease with rainbow trout % biomass ($P = 0.08$) but increase with % biomass of cutthroat trout ($P = 0.02$). Based on these correlations it appears that rainbow trout have a negative influence on tiger trout whereas cutthroat trout appear to have less influence.

The salmonid competition model was parsimonious ($\Delta AIC_c = 0.00-1.09$; Table 4) for all performance metrics except CPUE > 380 mm. Adjusted r^2 values for these metrics were low (≤ 0.06) indicating that a very low percentage of the variation in the data was explained by salmonid competition. Thus, overall it appears that salmonid competition is a poor predictor of tiger trout performance. Interestingly, the adjusted r^2 for salmonid competition was relatively high (0.17) when CPUE > 380 mm was evaluated. In this case salmonid competition was not deemed parsimonious by the AIC analysis because the lake production model was significantly stronger (Table 4).

The salmonid competition model contained the combined effect of rainbow, cutthroat, and "other trout". Table 5 shows the results from additive linear models that were constructed to parse out the effect of these species on tiger trout. The conclusions from these models are similar to the univariate correlations. Tiger trout total length tends to increase with increasing tiger trout % community composition. Thus tiger trout tend to grow well in systems where they are the dominant salmonid. In contrast tiger trout biomass and CPUE > 380 mm tended to decrease with increasing rainbow trout biomass. Thus tiger trout tend to do poorly in rainbow trout dominated reservoirs.

4) What effect does increasing the stocking size and number have on net catch rates?

Increasing the number of tiger trout stocked or average length at the time of stocking has less of an effect on gill net CPUE or the percentage biomass in a reservoir that was tiger trout than other factors. When CPUE and biomass were evaluated as performance metrics in the AIC, ΔAIC values were 1.93-2.11 (Table 4). Adjusted r^2 values across performance metrics were ≤ 0.06 indicating that a low amount of variability in the data is explained by these stocking characteristics. Univariate correlations (Table 3) show that increasing the number of tiger trout stocked and length at the time of stocking had no effect on performance. The timing of stocking also had no influence on tiger trout performance (all $P \geq 0.41$).

5) How does prey availability effect tiger trout performance?

Unfortunately we lack the data necessary to have a complete understanding of how prey availability affects tiger trout performance. It is likely that tiger trout consume invertebrate prey initially after stocking and later switch to piscivory as they grow larger. This is supported by data from P. Budy (Utah State University) who found that tiger trout stocked into Scofield Reservoir shifted to piscivory at around 340 mm (Personal Communication). The maximum average length of fish stocked into any of our study reservoirs was 148 mm. Therefore this data suggests that tiger trout would have to live off of other forms a prey for awhile before this shift towards piscivory occurred. Unfortunately, we do not have any data on invertebrate abundance in any of the reservoirs and we only have data on prey fish species that are large enough to be captured in gill nets. These fish are represented as the "interspecific competition" model in the AIC analysis (Table 4) and competition with these other species had a ΔAIC values of 0.00-2.03 for all of our performance metrics except the CPUE of tiger trout larger than 380 mm (ΔAIC = 14.34). Adjusted r^2 values for this model ranged from 0.00-0.02 indicating that interspecific competition explained little variation in the data. The β weights for these models tended to be negative (Table 4). This suggests that these other species may not necessarily provide prey for tiger trout and instead they may compete directly with tiger trout for prey resources. This seems to corroborate Budy's work. The one exception is that the β weight was positive when tiger trout survival was assessed (Table 4). This may be an indication that conditions conducive to high survival of these non-salmonid fishes may contain the same resources required for high tiger trout survival.

6) How does angler harvest influence tiger trout success?

Tiger trout are very popular among Utah's anglers and it is possible that angler harvest has a significant effect on tiger trout survival. Unfortunately we did not have access to creel data and therefore it is not possible to address this question in this study.

7) Do tiger trout impact the performance of other fish species?

We did not compute a complete set of metrics (length, condition, survival, biomass, and CPUE) for all fish species collected in the gill nets. Part of the reason why we did not do this is because some species were relatively uncommon (e.g., kokanee salmon) and because we did not have a comprehensive dataset for all these species. The univariate correlations shown in Table 3, however, provide a partial understanding of any effects that tiger trout have on other species. In general, the correlations among other salmonid species CPUE and biomass and non-salmonid CPUE and biomass with the tiger trout performance metrics were weak. This provides an indication that tiger trout have little effect on these other species. The CPUE of other salmonids increased with the CPUE of tiger trout >380 mm ($r = 0.58$, $P = 0.03$). This suggests that conditions that are conducive to supporting large tiger trout also support a high abundance of other salmonids. This is an indication that tiger trout are not consuming or competing with other salmonids in these systems. Also the CPUE of other salmonids tended to slightly decrease with increasing tiger trout percent biomass ($r = -0.49$, $P = 0.07$). This could be a sign of competition but alternatively, you would expect the CPUE of other salmonids to be lower in systems where tiger trout make up a significant portion of the fish community.

8) Can past tiger trout performance and stocking history be used to predict future tiger trout success?

This question was assessed by fitting two sets of additive linear models. The first set determined whether the number of fish stocked one year (assessed as #/ha) can be used to predict the CPUE of fish during the next year. The second set of models was used to determine whether data from the previous two years of stocking can be used to predict CPUE. For the first set of models, CPUE during the first year was not related to CPUE during the next year ($F_{1,6}$ = 0.05, *P* = 0.83). The numbers of fish stocked during this first year did not significantly improve the fit of the model ($F_{1,5}$ = 2.91, *P* = 0.16). Similarly, adding the number of fish stocked during the second year did not improve model fit ($F_{1,4}$ = 0.12, *P* = 0.75). For the second set of models CPUE was a poor predictor of CPUE two years later ($F_{1,4}$ = 0.28, *P* = 0.62) and adding stocking numbers did nothing to improve model fit (*P* -values 0.50-0.86).

These data suggest that there is a poor relationship between the number of fish stocked (measured as #/ha) and gill net CPUE. Thus stocking more fish may not be a sure-fire way to increase the CPUE of tiger trout within a reservoir. Clearly many factors interact to help determine the success of tiger trout. There are a few trends in the data that may have prevented us from observing a relationship between stocking and CPUE. Primarily, the number of tiger trout stocked into all of our study reservoirs decreased by at least 50% during our study period. CPUE of tiger trout in all of our study reservoirs also decreased by 6-97% during the same period. A notable exception was Panguitch Lake which experienced a 254% increase in tiger trout CPUE during the same period. Regardless, the lack of reservoirs where stocking numbers and CPUE increased likely limited the strength of this analysis.

The average stocking density of tiger trout in the study reservoirs in 2010 was 319 ± 236/ha (mean ± SD) and this decreased to 100 ± 75/ha in 2011 and 133 ± 98/ha in 2012. Although not statistically significant, It seems possible that that this decrease in stocking numbers is at least partially responsible for the decreased CPUE observed. It is possible that the stocking densities used in 2011 and 2012 are not sustainable and could lead to continued decreases in tiger trout CPUE.

One important note is that the average length of tiger trout at the time of stocking (100 ± 29 mm) is considerably smaller than the average length captured in the gill nets (344 ± 98 mm). Thus tiger trout must grow significantly after stocking before they can be effectively captured in the gill nets. This implies that a time lag occurs between when tiger trout are stocked and when they can be captured. This lag may contribute to the poor fit between our stocking data and CPUE.

Management Recommendations

Our data shows that reservoir productivity and competition are important factors influence tiger trout performance in Utah's reservoirs. It appears that tiger trout perform well in warmer, clearer reservoirs and that they perform poorly in reservoirs that have a high abundance of rainbow trout. In addition, our data seems to indicate that the CPUE and biomass of non-salmonid forage fish has little effect on tiger trout performance. Thus tiger trout may not be as piscivorous as thought and may not have the same effect on nuisance species such as Utah chub as Bear Lake cutthroat trout. We found a poor correlation between the number of tiger trout stocked and the performance metrics. Obviously since tiger trout are sterile their populations are supported entirely by stocking. So, stocking must affect tiger trout CPUE. It appears that stocking levels used in 2011 and 2012 are potentially too low and have led to decreases in tiger trout CPUE. As a result, we recommend stocking more fish into systems where more tiger trout are desired. Our data shows little evidence that tiger trout compete with one another. Thus the carrying capacity for tiger trout must be high and has not been met in Utah's reservoirs.

Future Study Recommendations

Many of the models assessed had a poor fit. This can likely be attributed to many factors that could be addressed in future research. First, this study can be improved by increasing the number of reservoirs included in the analysis. Next the analysis is missing creel and invertebrate density data. These two factors may significantly affect tiger trout and should be included in future studies. To our knowledge these data has not been collected in our study reservoirs (at least during the period ranging from 2009-2012). Additionally, it would be helpful to mark fish at stocking to indentify cohorts upon recapture. Then growth could be estimated for different year classes and compared among years, species, reservoir types, etc. Finally, it would be beneficial if reservoir productivity data was collected during the same time period when fish sampling was performed.

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Table 1: List of reservoirs included in a multivariate analysis on factors influencing tiger trout performance in Utah's reservoirs.

Reservoir Name
Birch Creek Reservoir
Causey Reservoir
Crouse Reservoir
Electric Lake
Fish Creek Reservoir
Forsyth Reservoir
Hyrum Reservoir
Koosharem Reservoir
Lost Creek Reservoir
Mantua Reservoir
Moon Lake
Panguitch Reservoir
Scofield Reservoir
Smith and Morehouse Reservoir
Spirit Lake
Whitney Reservoir

Table 2: List of models used in an AIC analysis to evaluate the effects of various variables on tiger trout length, condition, survival, biomass, and catch per unit effort. All seven models used in the remaining evaluations.

Model Name	**Included Variables**
Reservoir Morphometry	Surface Area : Maximum Depth ratio
Reservoir Production	Temperature, Secchi Depth
Tiger Trout Stocking Characteristics	Average # Stocked/ha, Average Length at Stocking
Intraspecific Competition	Tiger Trout % Biomass
Other Salmonid Competition	% Biomass of all Salmonid Species other than Tiger Trout
Interspecific Competition	% Biomass of all Non-salmonid species
Intraspecific + Other Salmonid + Interspecific Competition	Tiger Trout % Biomass, Other Salmonid % Biomass, Non-Salmonid % Biomass

Table 3: Correlation matrix showing the results of univariate correlations of the environmental variables against the tiger trout performance metrics. Coefficients of determinations (r) are shown and the respective *P*-values are in parentheses. TT is an abbreviation for tiger trout. Temp is an abbreviation for temperature, CPUE represents catch per unit effort (# collected/net·night), chla represents chlorophyll α concentration, phos is an abbreviation for phosphorous concentration, and cutt represents cutthroat. Note, temperature was not actually measured. Instead the temperature metric is based on an ordination among latitude, elevation, and reservoir surface area. Low ordination values are associated with warm temperatures and high values are associated with cool temperatures. Thus the correlation coefficients for temperature are opposite of what is expected. For example, the correlation between temperature and length is negative (r = -0.54). Normally this would be interpreted as length decreasing as temperature increases. In this case this signifies that length increases at temperature increases. The correlations for all other variables are as expected. For example, the negative correlation between length and latitude (r = -0.61) signifies that length decreases as latitude increases.

Tiger Trout Metric	Temp.	Latitude	Max. Depth	Surface Area	Area : Depth	Chla.	Secchi Depth	# Stocked/ ha	Mean Stock Length	Mean Stocking Date	Salmonid (not TT) CPUE	Salmonid (not TT) Biomass	Non-salmonid Biomass	Non-salmonid CPUE	Rainbow Biomass	Cutt. Biomass
Length	-0.54 (0.03)	-0.61 (0.01)	-0.10 (0.71)	-0.10 (0.71)	-0.04 (0.87)	0.21 (0.44)	0.09 (0.74)	-0.15 (0.58)	-0.17 (0.54)	-0.20 (0.47)	0.04 (0.87)	-0.28 (0.29)	-0.12 (0.64)	0.02 (0.93)	-0.45 (0.08)	0.57 (0.02)
Condition	-0.12 (0.66)	0.08 (0.78)	-0.09 (0.75)	-0.09 (0.75)	-0.05 (0.86)	-0.18 (0.51)	-0.07 (0.79)	0.15 (0.57)	-0.17 (0.52)	-0.20 (0.44)	0.21 (0.44)	0.35 (0.18)	-0.04 (0.87)	-0.01 (0.96)	-0.08 (0.76)	-0.24 (0.37)
Survival	0.01 (0.96)	-0.01 (0.98)	0.35 (0.18)	0.35 (0.18)	0.07 (0.78)	-0.46 (0.07)	0.25 (0.36)	-0.13 (0.63)	0.27 (0.31)	0.15 (0.57)	0.29 (0.28)	-0.03 (0.92)	0.09 (0.74)	0.06 (0.80)	-0.18 (0.51)	-0.26 (0.34)
Biomass	-0.40 (0.13)	-0.41 (0.12)	-0.16 (0.56)	-0.16 (0.56)	-0.17 (0.52)	-0.07 (0.80)	0.24 (0.36)	-0.31 (0.24)	-0.20 (0.46)	-0.18 (0.50)	-0.03 (0.90)	-0.18 (0.51)	-0.22 (0.43)	-0.26 (0.33)	-0.43 (0.09)	-0.24 (0.34)
CPUE	-0.06 (0.84)	-0.02 (0.95)	0.03 (0.91)	0.03 (0.91)	-0.24 (0.37)	-0.32 (0.23)	0.53 (0.04)	0.24 (0.38)	0.33 (0.21)	0.22 (0.41)	0.23 (0.38)	-0.20 (0.44)	-0.15 (0.53)	-0.12 (0.64)	-0.37 (0.16)	-0.31 (0.24)
CPUE > 380 mm	-0.46 (0.07)	-0.54 (0.03)	0.17 (0.52)	0.17 (0.52)	-0.12 (0.66)	0.09 (0.74)	0.71 (<0.01)	-0.01 (0.96)	0.15 (0.59)	0.08 (0.76)	0.21 (0.44)	-0.47 (0.06)	-0.18 (0.51)	-0.04 (0.87)	-0.45 (0.08)	0.05 (0.87)

Table 4: Summary statistics from an AIC analysis that was performed to determine the effect that reservoir morphometry, reservoir production, fish stocking, and various measures of competition have on the total length, condition, survival, biomass, and catch per unit effort (CPUE) of tiger trout across 16 Utah reservoirs. The adjusted r^2 for each model is shown. Also, all of the variables and their respective β weights, t-values, and *P*-values are shown for each model. As a note, the variable temperature was derived using an ordination among latitude, elevation, and reservoir surface area. All summary statistics shown for temperature are correct but caution should be taken when interpreting the direction (+ or -) of the β weights for temperature. Positive values for temperature are associated with higher latitudes, higher elevations, and larger surface areas. Thus positive "temperature" β weights are actually associated with cooler temperatures and negative β weights are associated with warmer temperatures. For example the β weight for the independent variable total length is negative (-0.56). This means that growth tended to increase as temperature increases. β weights for all other variables can be considered normal (i.e., growth, condition, etc. all increase when the β weight for a variable is positive and decrease when a β weight is negative).

Independent Variable	Model Name	ΔAIC	Model Adjusted r2	Variable Name	β	t	P
Total Length	Lake Morphometry	2.05	0.01	Area:Depth	-0.04	0.16	0.87
	Lake Production	0.00	0.19	Temperature	-0.54	2.33	0.04
				Secchi Depth	0.06	0.28	0.79
	Stocking Characteristics	4.78	0.01	# Stocked/ha	-0.17	0.63	0.54
				Mean Stock TL	-0.19	0.69	0.50
	Intraspecific Competition	1.83	0.01	TT CPUE	0.13	0.48	0.64
	Salmonid Competition	0.80	0.02	Salmonid CPUE	-0.28	1.08	0.30
	Interspecific Competition	1.85	0.01	Non Salmonid CPUE	-0.12	0.46	0.65
	Total Competition	7.66	0.01	Tiger Trout CPUE	0.00	0.01	0.99
				Salmonid CPUE	-0.39	1.27	0.23
				Non Salmonid CPUE	-0.28	0.90	0.39
Condition (K)	Lake Morphometry	2.01	0.01	Area:Depth	-0.05	0.18	0.86
	Lake Production	5.36	0.01	Temperature	-0.12	0.45	0.66
				Secchi Depth	-0.08	0.28	0.79
	Stocking Characteristics	4.89	0.00	# Stocked/ha	0.14	0.50	0.63
				Mean Stock TL	-0.16	0.58	0.57
	Intraspecific Competition	2.02	0.00	TT Biomass	-0.05	0.18	0.86
	Salmonid Competition	0.00	0.06	Salmonid Biomass	0.35	1.38	0.19
	Interspecific Competition	2.03	0.00	Non Salmonid Biomass	-0.04	0.14	0.88
	Total Competition	7.73	0.01	Tiger Trout Biomass	0.06	0.20	0.84
				Salmonid Biomass	0.41	1.34	0.20
				Non Salmonid Biomass	0.14	0.44	0.67

Survival	Lake Morphometry	0.08	0.01	Area:Depth	0.07	0.28	0.78
	Lake Production	2.79	0.01	Temperature	0.03	0.10	0.92
				Chlorphyll α	-0.47	0.92	0.37
	Stocking Characteristics	2.39	0.01	# Stocked/ha	-0.10	0.39	0.71
				Mean Stock TL	0.26	0.98	0.35
	Intraspecific Competition	0.00	0.01	Tiger Trout Biomass	-0.10	0.39	0.70
	Salmonid Competition	0.16	0.00	Salmonid Biomass	-0.03	0.10	0.92
	Interspecific Competition	0.04	0.01	Non Salmonid Biomass	0.09	0.34	0.74
	Total Competition	7.91	0.00	Tiger Trout Biomass	-0.09	0.31	0.77
				Salmonid Biomass	-0.02	0.06	0.95
				Non Salmonid Biomass	0.06	0.19	0.85
Biomass	Lake Morphometry	0.62	0.01	Area:Depth	-0.17	0.66	0.52
	Lake Production	1.02	0.09	Temperature	-0.38	1.56	0.14
				Secchi Depth	0.23	0.92	0.38
	Stocking Characteristics	2.11	0.02	# Stocked/ha	-0.38	1.31	0.21
				Mean Stock TL	0.23	0.91	0.38
	Intraspecific Competition	1.09	0.00	Tiger Trout CPUE	-0.03	0.11	0.91
	Salmonid Competition	1.09	0.00	Salmonid CPUE	-0.03	0.13	0.90
	Interspecific Competition	0.00	0.02	Non Salmonid CPUE	-0.26	1.00	0.33
	Total Competition	7.47	0.01	Tiger Trout CPUE	-0.03	0.11	0.92
				Salmonid CPUE	-0.19	0.59	0.57
				Non Salmonid CPUE	-0.35	1.13	0.28
CPUE	Lake Morphometry	0.62	0.01	Area:Depth	-0.24	0.94	0.37
	Lake Production	0.00	0.17	Temperature	-0.03	0.13	0.90
				Secchi Depth	0.52	2.23	0.04
	Stocking Characteristics	1.93	0.06	# Stocked/ha	0.28	1.10	0.29
				Mean Stock TL	0.36	1.44	0.17
	Intraspecific Competition	1.58	0.00	TT Biomass	-0.03	0.11	0.91
	Salmonid Competition	0.91	0.02	Salmonid Biomass	-0.20	0.78	0.45
	Interspecific Competition	1.24	0.01	Non Salmonid Biomass	-0.15	0.56	0.58
	Total Competition	7.38	0.01	Tiger Trout Biomass	-0.17	0.58	0.57
				Salmonid Biomass	-0.37	1.19	0.26
				Non Salmonid Biomass	-0.33	1.07	0.31

CPUE > 380 mm	Lake Morphometry	14.62	0.01	Area:Depth	-0.12	0.44	0.66
	Lake Production	0.00	0.64	Temperature	-0.43	2.77	0.02
				Secchi Depth	0.69	4.40	<0.01
	Stocking Characteristics	18.12	0.01	# Stocked/ha	0.00	0.00	0.99
				Mean Stock TL	0.15	0.54	0.60
	Intraspecific Competition	14.34	0.02	TT Biomass	0.18	0.67	0.51
	Salmonid Competition	10.79	0.17	Salmonid Biomass	-0.47	2.00	0.06
	Interspecific Competition	14.34	0.02	Non Salmonid Biomass	-0.18	0.67	0.51
	Total Competition	15.16	0.22	Tiger Trout Biomass	-0.04	0.16	0.87
				Salmonid Biomass	-0.66	2.53	0.02
				Non Salmonid Biomass	-0.44	1.70	0.11

Table 5: Effect of rainbow trout, cutthroat trout, and "other" trout (all other trout species) combined on the length, condition, survival, biomass, total CPUE, and CPUE of tiger trout > 380 mm TL. Weighted variable β values, t-values, and *P*-values are shown.

Independent Variable	Adjusted r^2	Model *P*-value	Species	β	t-value	Variable *P*-Value
Total Length	0.32	0.05	Rainbow	-0.36	1.70	0.12
			Cutthroat	0.58	2.54	0.03
			Other	-0.12	0.53	0.60
Condition (K)	0.01	0.74	Rainbow	0.01	0.05	0.96
			Cutthroat	-0.32	1.09	0.30
			Other	0.21	0.71	0.49
Survival	0.01	0.65	Rainbow	-0.12	0.42	0.68
			Cutthroat	-0.35	1.19	0.26
			Other	0.21	0.73	0.48
Biomass	0.26	0.09	Rainbow	-0.60	2.70	0.02
			Cutthroat	0.02	0.09	0.93
			Other	-0.30	1.25	0.23
CPUE	0.06	0.31	Rainbow	-0.39	1.55	0.15
			Cutthroat	-0.35	1.29	0.22
			Other	0.01	0.05	0.97
CPUE > 380 mm	0.38	0.03	Rainbow	-0.66	3.07	<0.01
			Cutthroat	0.18	0.79	0.45
			Other	-0.08	0.36	0.72